BIOLOGICAL ASPECTS RELATING TO THE IXTOC I OIL SPILL

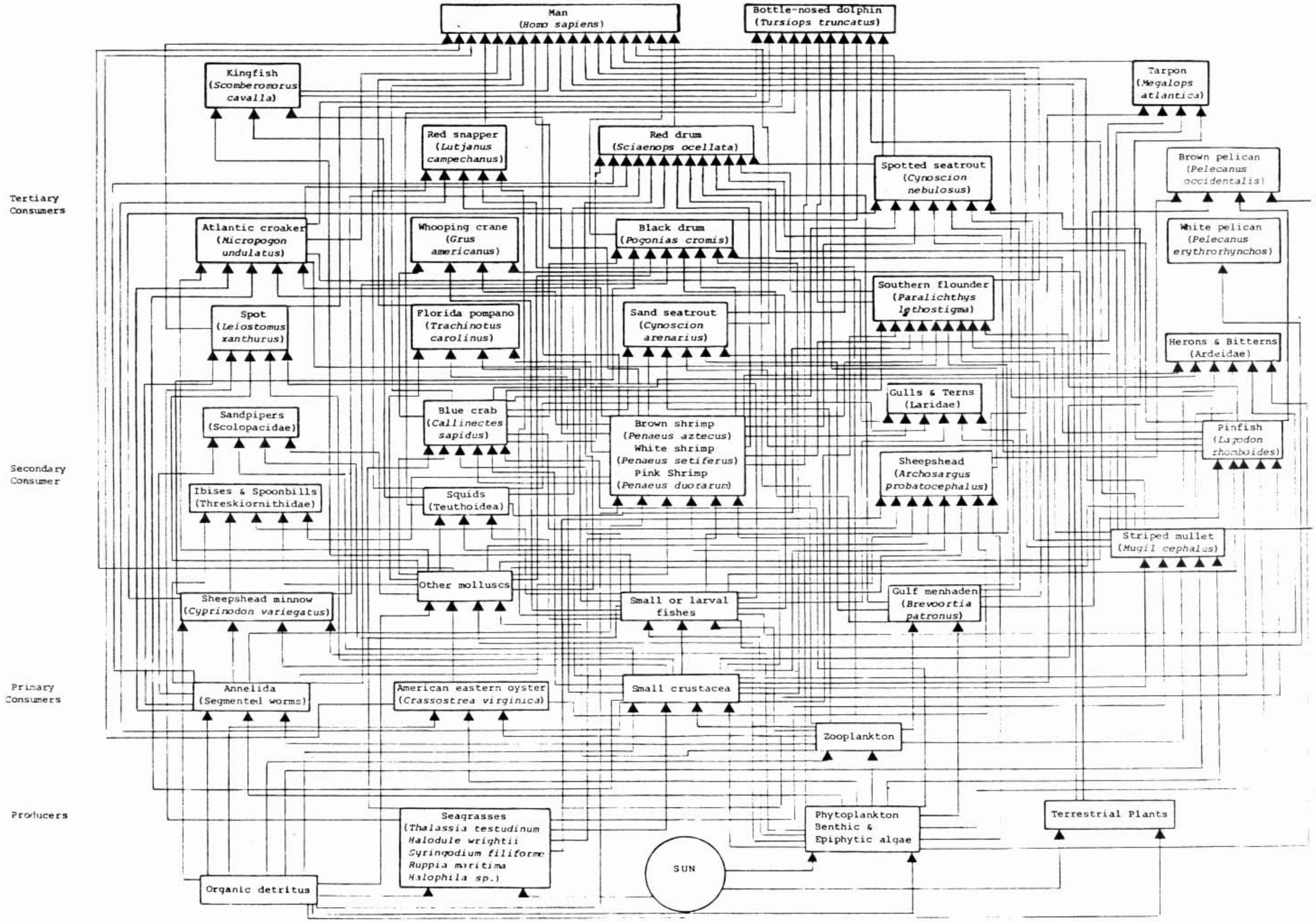
The following assembled materials review the biological information pertinent to an understanding of the possible effects of the Ixtoc I oil spill on the ecology of the Texas Gulf coast. Included are: a diagram of the trophic relationships of important species; a chart relating the spawning patterns of these species; individual species accounts revealing general temporal and spatial distributions and concentrations; a comprehensive list of South Texas Gulf coast fishes; a table of commercial fish landings from Texas coastal waters; and a review of the known effects of oil on biological systems.

It has been necessary to choose only the most relevant data on a selection of the most important species. Many species that occur in the Gulf region have been omitted to make this report more comprehensible. Complete lists of algae and molluscs for the entire Gulf coast along with distribution and habitat records, are available at TSNL. Also available is a nearly complete list of all other Gulf coast organisms.

Although oil pollution is a relatively new problem, entire monthly journals are devoted to its study and, each year, the amount of published literature on the subject has shown an amazing proliferation. To review all of the literature is therefore impossible, and only certain references have been chosen. Other review papers have been utilized to some extent. A complete bibliography for this report is available from TSNL.

Figure 1. FOODWEB CHART
NORTHWESTERN GULF OF MEXICO
TEXAS COASTAL ZONE

Figure 1 represents a small portion of the food web dealing primarily with the region encompassing the South Texas coast. Arrows follow the direction of the producer-consumer or prey-predator relationships, always advancing towards successively higher trophic levels. The sun is also included due to its role as the primary energy source for the photosynthetic processes carried out by the producers.


Tertiary Consumers
Secondary Consumer
Primary Consumers
Producers
Man (Homo sapiens)
Bottle-nosed dolphin (Tursiops truncatus)
Kingfish (Scomberomorus cavalla)
Tarpon (Megalops atlantica)
Red snapper (Lutjanus campechanus)
Red drum (Sciaenops ocellata)
Spotted seatrout (Cynoscion nebulosus)
Brown pelican (Pelecanus occidentalis)
Atlantic croaker (Micropogon undulatus)
Whooping crane (Grus americanus)
Black drum (Pogonias cromis)
White pelican (Pelecanus erythrorhynchos)
Southern flounder (Paralichthys lethostigma)
Spot (Leiostomus xanthurus)
Florida pompano (Trachinotus carolinus)
Sand seatrout (Cynoscion arenarius)
Herons & Bitterns (Ardeidae)
Gulls & Terns (Laridae)
Sandpipers (Scolopacidae)
Blue crab (Callinectes sapidus)
Brown shrimp (Penaeus aztecus) White shrimp (Penaeus setiferus) Pink Shrimp (Penaeus duorarum)
Pinfish (Lagodon rhomboides)
Sheepshead (Archosargus probatocephalus)
Ibises & Spoonbills (Threskiornithidae)
Squids (Teuthoidea)
Striped mullet (Mugil cephalus)
Other molluscs
Sheepshead minnow (Cyprinodon variegatus)
Small or larval fishes
Gulf menhaden (Brevoortia patronus)
Annelida (Segmented worms)
American eastern oyster (Crassostrea virginica)
Small crustacea
Zooplankton
Seagrasses (Thalassia testudinum Halodule wrightii Syringodium filiforme Ruppia maritima Halophila sp.)
Phytoplankton Benthic & Epiphytic algae
Terrestrial Plants
SUN
Organic detritus

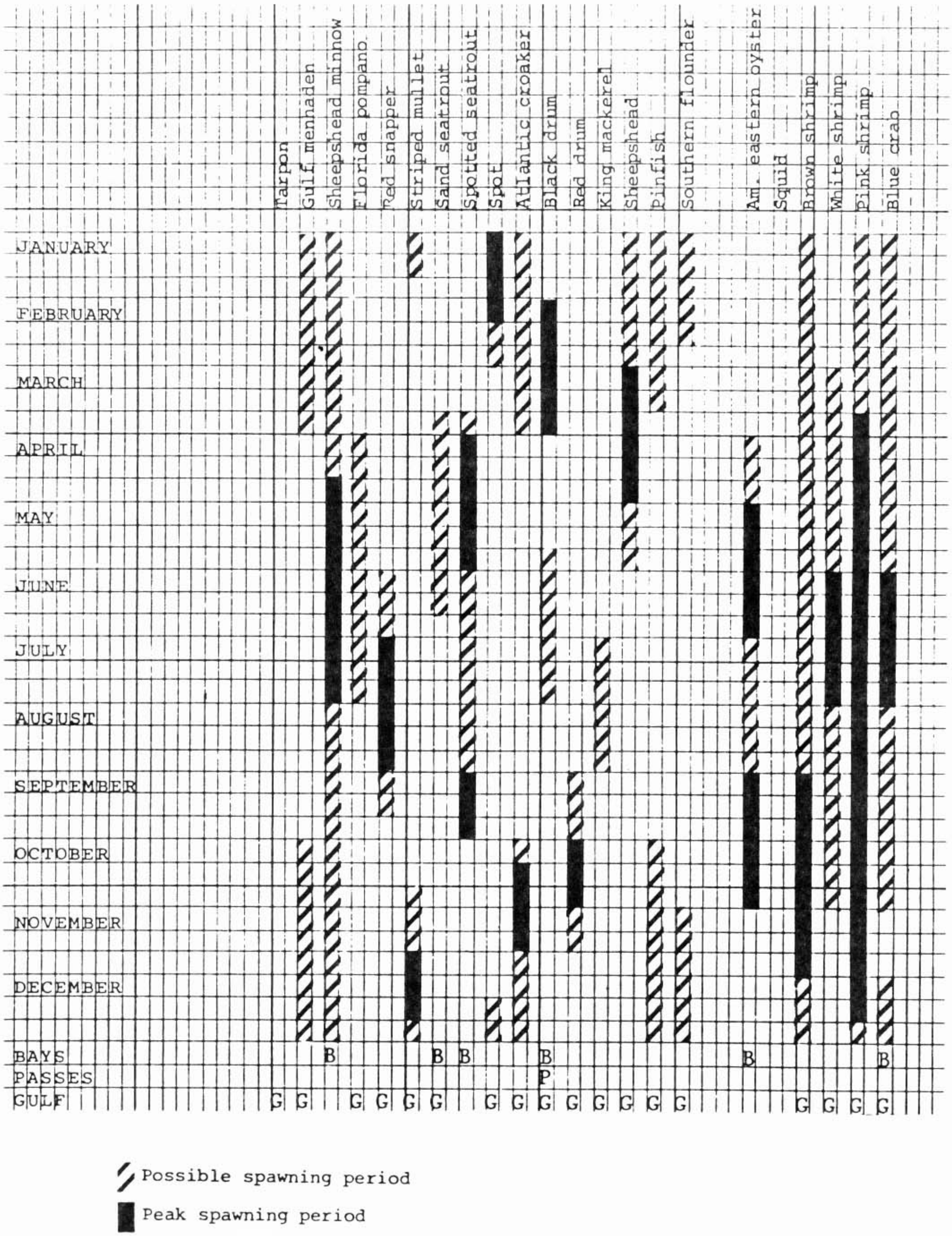
FOOD WEB

Figure 1 represents a small portion of the food web found within the great expanse of the Gulf of Mexico. The purpose of such an illustration, with respect to possible damage to one or any number of the given organisms by oil, becomes apparent when the impact throughout the food web of such an occurrence is examined. The figure, in addition to providing insight into interspecific trophic relationships, also establishes an hierarchy whereby, at a glance, one can estimate the approximate trophic level occupied by any given species, i.e. producer, primary consumer, secondary consumer, tertiary consumer, as well as intermediate levels. Most of the organisms included on the chart were chosen from those which were considered to be most valuable to man from a commercial, recreational or aesthetic standpoint. However, many of the taxonomic groupings, as well as some of the individual species, were included solely as an aid in understanding the food web as a whole. Some possibly significant species or groups have been excluded due to the limited amount of information available as well as the need to limit the scope of such a project. It is for this reason that amphibians and reptiles, as well as small land mammals, were excluded, in spite of their importance to the diet of many of the shorebirds. Each of the arrows on the chart represents data extracted from one or several different references. Omitted arrows, where one might, in fact, expect trophic relationships to exist, have resulted from the lack of sufficient documentation within the researched literature to support their inclusion. Man and the bottle-nosed dolphin were placed at the head of the figure since neither is severely threatened by any known predator and both reach a larger adult size than most of the fishes found below them in the hierarchy. However, man's role as an omnivore is also considered with the addition of terrestrial plants as a food item.

Although it might seem somewhat tedious to attempt tracking down all of the trophic relationships involving a given species by following the lines, the value of such a figure lies more in its ability to present the information as it relates to the food web as a whole rather than simply as one small piece of data. As an example, one can readily see the large concentration of lines leaving the centrally located shrimp species which, in turn, can be interpreted as demonstrating their greater relative value to the stabilization of the food web as a whole. However, the exclusion of the white or brown pelican could be seen as having less of an obvious impact on the other species found within the web.

In several cases, such as with the croaker, kingfish (king mackerel), red snapper and spot, reference to an item in the diet consisting of "fish" was slightly modified and represented by the category "small or larval fishes" due to the lack of a separate category which included adults. The obvious cases of cannibalism found within the larger groups such as molluscs and crustaceans as well as among the individual species were not included.

Figure 2. TEMPORAL AND SPATIAL REPRESENTATION OF SPAWNING CHARACTERISTICS AMONG IMPORTANT SPORT AND COMMERCIAL FISHES AND INVERTEBRATE SPECIES ALONG THE SOUTH TEXAS COAST



SPAWNING ACTIVITY

Figure 2 is provided to enable the speedy determination of spawning time and site for those species mentioned as the most valuable sport and commercial fishes and shellfishes of the Texas coast. Due to the increased susceptibility of the larval stages of most organisms to the toxic effects of oil (Sanborn, 1977), such a determination is necessary when assessing possible damage to a given population or species group.

The months of the year, listed down the left column, are divided into thirds representing approximate 10-day periods to enable a more precise representation of spawning time. As indicated in the key, cross-hatching is used to indicate possible spawning time, while the darkened portions represent peak spawning periods as determined through the literature. Often a given period is representative of the cumulation of data from several different sources and may not refer to any one statement. This was necessary since authors quite often differ with respect to the beginning and cessation dates for the respective spawning periods. Spawning sites are indicated using the letters B, P and G referring, in that order, to the bays, passes and the Gulf of Mexico. Fish and invertebrate species have been listed in taxonomic sequence (down to order) which facilitates comparison of this figure with the species synopses which follow.

SPECIES ACCOUNTS

In an attempt to provide the additional information needed to establish the temporal and spatial distributions and concentrations of those fishes and invertebrates found in Figure 2, the following short synopses were assembled. Information with regard to preferred habitats, migrational patterns, relative abundance, as well as additional reproductive information not included in Figure 2, is provided. Following the species accounts, a comprehensive list of fishes of the South Texas coast, as well as offshore forms, has been included. This, as well as more specific distributional information by bay system, can be found in the TSNL publication Fishes of Coastal Texas. Table I, a compilation of previously published Texas Parks & Wildlife Commercial Fish Landings reports, has also been included listing yearly averages for both Gulf and bay commercial landings in both pounds and dollars for the six year period beginning in September 1972 and terminating in August 1978.

TARPON - *Megalops atlantica*

Although tarpon populations have declined in numbers since they were first fished along the Texas coast, in recent years they have made a comeback and have begun to reappear moving up and down the coast as previously reported (Dutch, 1975). The reason for their temporary absence has not yet been determined, although some say it might have been due to the generalized increase in pollutants of the area (Dutch, 1975). Tarpon prefer coastal marine areas, often entering brackish water and sometimes rivers (Knapp, 1953; Jones, Martin, and Hardy, 1978). Movements along shore coincide with spring migrations of the silverside mullet, a preferred food item, along the lower coast (Dutch, 1975). Very little is known of their spawning activity along the Texas coast.

GULF MENHADEN - *Brevoortia patronus*

Gulf menhaden are very abundant along the Texas coast, moving into the bays through the passes as young, from winter until early spring, after which many emigrate back to the Gulf in the fall (TPWD, 1978). Menhaden are strictly surface forms (Hoese, 1965) relying heavily on a planktonic diet. Though of little value as a sport fish (TPWD, 1978) they are relatively important as food to many of the commercial fishes of greater interest to man. The eggs are buoyant (James, Martin, and Hardy, 1978) and are found from the beaches to offshore (Hoese, 1965; TPWD, 1978) from midwinter to early spring (Gunter, 1945; Miller, 1965).

SHEEPSHEAD MINNOW - *Cyprinodon variegatus*

These small fish can be found mostly in shallow salt marsh areas bordering on Texas bays (Gunter, 1950; Moore, 1958; Strawn and Dunn, 1967; Hoese and Moore, 1977). Having the greatest salinity tolerance of any known fish, they often inhabit extreme environments (Hoese and Moore, 1977; Hardy, 1978a). Movements are usually restricted to migrations towards warmer and slightly deeper water in the fall (Gunter, 1945) although Hardy (1978a) mentions limited inshore and offshore movements in April, May and November on the Texas coast. Hardy (1978a) also states that the fish tend to enter bayous during the colder months and bays during the warmer periods. Peak abundance seems to occur during the winter and spring (Gunter, 1945; TPWD 1975b; Johnson, 1977). The eggs of the sheepshead minnow are "demersal, adhesive or semi-adhesive, sticking to plants, stuck to each other, or at times partially buried in the bottom" (Hardy, 1978a). Spawning takes place in the shallow areas of bays, large tidepools, mangrove lagoons, and pools, over bottoms of sand, black silt, or mud (Hardy, 1978a).

FLORIDA POMPANO - *Trachinotus carolinus*

The Florida pompano inhabits primarily the Gulf beach surf zone (Reid, Inglis, and Hoese, 1956; McFarland, 1963; Pew, 1966; Hoese and Moore, 1977) although large fish are sometimes found within the bays (Gunter, 1944). Peak abundance of young pompano occurs in the summertime during

July, August, and September (Gunter, 1945) with fewer numbers reported during the winter months (Johnson, 1978). Although little information on migration patterns in the Gulf of Mexico exists, the eastern Atlantic population appears to move northward during the spring and summer (Johnson, 1978). The Florida pompano is considered by many the most delicious of all fishes (Pew, 1966).

RED SNAPPER - *Lutjanus campechanus*

In recent years the red snapper has become one of the most sought after sport fishes of the Gulf coast (Moseley, 1965). Considered a reef dwelling species, most individuals occur in the offshore Gulf (TPWD, 1978). Commercial data indicate that adults are not strictly confined to irregular or hard bottoms (Moseley, 1965) and juveniles, in fact, are usually found widely distributed over muddy and sandy bottoms (Moseley, 1965; TPWD, 1978). Spawning probably occurs offshore with some "inshore transport of larvae and juvenile stages" (Moseley, 1965). Although definite migrations have not been substantiated, some offshore movements in the winter and inshore movements in the summer have been observed (Hardy, 1978b). It has also been suggested that "as snappers grow they seek deeper water" (Moseley, 1965). Declining landings in recent years may be an indication of declining populations (Arnold, et al., 1978).

STRIPED MULLET - *Mugil cephalus*

One of the truly euryhaline fishes, the striped mullet is found in nearly all environments from fresh water rivers to hypersaline flats and shallows (Gunter, 1945; Reid, Inglis, and Hoese, 1956; Hoese and Moore, 1977; TPWD, 1978). During the ebb tide at night they are known to concentrate in large numbers along the shallow waters adjacent to beaches (Reid, Inglis, and Hoese, 1956; Fuls, 1974). Migrations consist of adults leaving the bays in large schools in the fall to spawn (Gunter, 1945; McFarland, 1963; TPWD, 1975f) and a return of smaller schools to the bays over a six-month period (Hoese and Moore, 1977). The larvae hatch from floating eggs although "some sinking of viable eggs" has been documented (Martin and Drewry, 1978). The young then migrate to the bays soon afterwards (TPWD, 1978). The striped mullet is one of the most abundant organisms in South Texas in both numbers and biomass (Hellier, 1961; McFarland, 1965; Moore, 1974; Hoese and Moore, 1977). They thus form a major link in the food web providing many of the marine carnivores with an abundant nutrient source.

SAND SEATROUT - *Cynoscion arenarius*

Although not especially abundant, the sand seatrout has become a significant sport fish along the Texas coast. It occurs in greatest numbers in the bays during the late summer and fall (Pew, 1966) with an abundance peak in the Gulf in December and January (Gunter, 1945; Parker, 1965; TPWD, 1975e). Gulfward migrations take place "only during cold weather" (TPWD, 1978). Spawning occurs in the deeper areas of the bays or the shallow Gulf, the young remaining over muddy bottoms (Hoese and Moore, 1977).

SPOTTED SEATROUT - *Cynoscion nebulosus*

Considered the "most sought after, most often caught sport fish on the coast" (TPWD, 1978), the speckled trout frequents bays and the shallow Gulf areas. Both adults and juveniles seem to prefer areas over dense vegetation, particularly *Thalassia* beds (Zimmerman, 1969; Johnson, 1978). Spawning occurs mostly at night in the deeper areas of the bays and lagoons (TPWD, 1975a; TPWD, 1975f; Hoese and Moore, 1977; Johnson, 1978). The eggs are initially buoyant becoming demersal after twelve hours and hatching after about forty hours (Johnson, 1978). The young remain in or near bottom vegetation (Hoese and Moore, 1977) seemingly preferring the "shell rubble of channel bottoms and the edges of grass flats" (Johnson, 1978). Migrations are limited to general gulfward movements as temperatures decline, the extent of movement usually depending on the severity of the winter (Stevens, 1978). Some fish actually enter the Gulf, although many simply seek out the deeper bay waters. During the warmer months the fish return to the inland bay areas. Sometimes a rapid decrease in salinity will cause them to seek out other areas (TPWD, 1975a). Although abundant year-round, the speckled trout is seen in greatest numbers during the warmer months (Parker, 1965; TPWD, 1975e).

SPOT - *Leiostomus xanthurus*

A very common bay and shallow Gulf species (Hoese and Moore, 1977), the spot seems to prefer mud and sand bottoms although as juveniles they are also quite abundant in *Thalassia* beds (Zimmerman, 1969; Johnson, 1978). Since spawning generally occurs in the Gulf near the passes, the young spread rapidly into the bays (Gunter, 1945). As the young fish mature they gradually move towards deeper water (Hoese & Moore, 1977) where they remain in the shallower lagoons and coves until temperatures drop, when they move to the deeper waters of the bays and Gulf (Johnson, 1978). Although very abundant in Texas bays throughout the year, they can also be found during the fall spawning season in the Gulf (TPWD, 1978).

ATLANTIC CROAKER - *Micropogon undulatus*

The Atlantic croaker is usually found over mud, sand, mud-sand mixtures, mud-shell mixtures and over "live" bottoms of mud-sand mixtures in the bays during the warmer months (Johnson, 1978). During the fall (September and October) adults migrate to the Gulf to spawn and remain there while the young return to the bays. Juveniles can tolerate colder temperatures better than the adult fish and thus remain in the upper reaches of the estuaries throughout the winter while most adults remain offshore (Johnson, 1978). Considered perhaps the "commonest bottom-dwelling estuarine species" (Hoese and Moore, 1977) the croaker is also spoken of as the most abundant individual species of food fish in the bays (TPWD, 1978).

BLACK DRUM - *Pogonias cromis*

The black drum seems to prefer the shallow waters of the bays (TPWD, 1975f; Hoese and Moore, 1977) and is most often found over sandy bottoms (Johnson, 1978). Nursery grounds usually occur in shallow vegetated regions (TPWD, 1975a) most often in muddy waters (TPWD, 1975f). Besides the pronounced spawning migrations towards the passes which occur in late winter and early spring, a period of heavy runoff can also initiate temporary movements into freshwater streams (Simmons and Breuer, 1962). The highest concentrations of the black drum are usually found in Corpus Christi Bay and the Laguna Madre (Simmons and Breuer, 1962). Peak abundance off Texas occurs from October through February (Johnson, 1978).

RED DRUM - *Sciaenops ocellata*

Adult redfish are usually solitary, living in the shallower waters of the bays (Hoese and Moore, 1977). Spawning migrations occur in the fall with actual spawning taking place in the Gulf near passes and channels (Johnson, 1978). The young immediately enter the bays (TPWD, 1978) where they seek out "clumps of grass or oyster shell over slightly muddy bottoms in quiet protected waters" (Johnson, 1978). These smaller fish usually remain in the bays even during the winter months (TPWD, 1978). In contrast, some of the largest redfish may stay offshore instead of returning to the bays in the spring as the young or other spawning adults do (Hoese and Moore, 1977). Thus, redfish movements can be characterized as either "broad random movements, loosely coordinated temperature migrations, or strong offshore migrations" (TPWD, 1975f).

KING MACKEREL - *Scomberomorus cavalla*

Although more common in deep clear water (Pew, 1966; Causey, 1969), the king mackerel has also been found to inhabit murky areas (TPWD, 1978). Off of Galveston, Freeport, and Port Arthur they are known to "congregate in large numbers around reefs" (Pew, 1966). These fish migrate in large schools along the Gulf coast throughout the summer months (Pew, 1966; TPWD, 1978), and their appearance is regarded by some as "the marine harbinger of summer" (Hoese and Moore, 1977). Very popular as an offshore sport fish it is often considered as the "very backbone of the offshore sport fishing along the Texas coast" (TPWD, 1978).

SHEEPSHEAD - *Archosargus probatocephalus*

Both adult and juvenile sheepshead seem to prefer vegetated areas such as *Thalassia* beds (Zimmerman, 1969) or other protected areas where shelter is abundant (TPWD, 1975f; TPWD, 1978). Adults, specifically, can be found frequenting "oyster beds and muddy shallow waters, particularly about inlets near piers, breakwaters, wrecks and often up rivers" (Johnson, 1978). Spawning occurs in the Gulf "near jetties, rock piles and reefs" (TPWD, 1978). The young hatch from floating eggs (TPWD, 1975f; Johnson, 1978) and enter the bays from late winter to early spring (TPWD, 1975f). Peak occurrence in the Upper Laguna Madre is from December to March (TPWD, 1975e) while in Galveston Bay it is during the months of May, June, July, and October (TPWD, 1975f).

PINFISH - *Lagodon rhomboides*

According to Reid, Inglis, and Hoese (1956) there exists a "high degree of association between this species and vegetated areas". Although the adults "prefer open waters as opposed to estuaries", vegetation is still the most important variable in habitat choice (Johnson, 1978). If vegetation is absent they seek some other form of shelter such as "rocks, pilings, etc." (Johnson, 1978). Pinfish migrate towards the Gulf in late summer and fall culminating in a late fall and winter spawning well offshore (Hoese, 1958; Miller, 1964; Cameron, 1969). It has been suggested by Cameron (1969) that perhaps this winter spawning is an adaptation to the grasses growing in the spring, for, from March to April, population levels increased sharply due to the influx of large numbers of juveniles into the grassflats (Zimmerman, 1969). These migration patterns are thus likely responsible for the peak abundance levels in the *Thalassia* beds during the spring, summer, and early fall and the lows during the late fall and winter (Zimmerman, 1969).

SOUTHERN FLOUNDER - *Paralichthys lethostigma*

Adult southern flounder are usually found within the bays and shallow Gulf (Hoese, 1958) over "softer mud bottoms" (Hoese and Moore, 1977). The juveniles are found in shallow bay areas sometimes venturing into lower salinities (Knapp, 1953; Hoese and Moore, 1977) and apparently avoid areas of high turbidity (TPWD, 1975a). Spawning migrations take place in the Gulf of Mexico during the fall (Stokes, 1975; TPWD, 1975f; Hoese and Moore, 1977; TPWD, 1978). Mass migrations can be triggered by a severe norther initiating this exodus out of the bays (Hoese and Moore, 1977). Young flounder begin to enter the estuaries in late winter and spring (Stokes, 1975; TPWD, 1975b; TPWD, 1975f; Johnson, 1977). The adults also return in the spring but more gradually than the fall outflux (Stokes, 1975). Johnson (1977) states that the southern flounder is "possibly the most common sport fish besides the Atlantic croaker in sport catches". However, bulkheading and other forms of shoreline destruction "may adversely affect the adults" (TPWD, 1975a).

AMERICAN EASTERN OYSTER - *Crassostrea virginica*

The American eastern oyster is found in shallow lagoons and estuarine waters attached to a hard or semihard substrate. Reefs, which are oyster colonies usually living on a substrate of discarded oyster shells, are generally found perpendicular to the prevailing currents in an area (Fotheringham and Brunenmeister, 1973). Each oyster on the reef is thus exposed to a flow of water carrying fresh supplies of food and oxygen. Oysters are still found in every bay along the Texas coast although their numbers have declined somewhat in recent years due to alteration of their habitat by man (TPWD, 1975b; TPWD, 1975c; TPWD, 1975d). Oysters do not migrate as adults, but their larvae are carried about by currents until they settle. When larvae reach the settling stage, they are known as "spat", and may control their movements to some extent by closing their valves and sinking to the bottom (TPWD, 1975f). Larvae must settle onto a hard substrate to survive to maturity (TPWD, 1975b). Spawning of adults is induced whenever the water temperature rises to 75^{o}F, therefore, on the Texas coast, spawning occurs between April and October (TPWD, 1975f).

SQUID - *Lolliguncula brevis*

This small squid species prefers relatively high salinities but will still enter the bays (Gunter, 1950). They enter the bays as the temperatures rise in late winter, remaining near the Gulf passes and returning to the Gulf in the fall (Gunter, 1950). Although little information is available concerning the time and site of spawning for this species along the Texas coast, it is known that "large numbers of *Loligo*", a closely related genus, "come together to copulate and spawn at the same time and a community pile of egg strings may be formed on the bottom" (Barnes, 1974).

BROWN SHRIMP - *Penaeus aztecus*

The importance of the brown shrimp to the Texas shrimp fishery is well documented, thus indicating the need for a thorough understanding of its life cycle. Spawning takes place throughout the year with a peak in the fall and perhaps an additional peak in the spring (Farfante, 1969). There is some evidence that the larvae "overwinter in nearshore waters and enter estuaries the following spring, probably surviving by burrowing" (Cook and Lindner, 1970). Once within the estuaries, the juveniles, bottom dwellers, seek out the marginal areas of estuarine waters before returning to the deeper waters of the estuaries in two to four weeks (Cook and Lindner, 1970). As adults, the brown shrimp leave the estuaries gradually, usually at night (Farfante, 1969). Some movement southward, parallel to the coast, may occur during the autumn and winter (Gunter, 1962). The adults usually prefer offshore substrates of mud or silt, sometimes of mud, sand or shell (Farfante, 1969). They generally inhabit waters of less than one meter to a depth of ninety-one meters (Gosner, 1971). Abundance varies from year to year (Cook and Lindner, 1970) and may be affected by a number of phenomena both natural and man-made. Floods and late cold spells as well as any adverse conditions within the estuaries during periods when the young are most abundant could prove detrimental to subsequent offshore catches (Cook and Lindner, 1970).

WHITE SHRIMP - *Penaeus setiferus*

Adult white shrimp are found offshore in shallower waters than the brown shrimp, usually at a depth of less than twenty-seven meters (TPWD, 1975b). They prefer substrates of soft mud or silt bottoms or "bottoms of clay or sand with fragments of shell" (TPWD, 1975b). Spawning also takes place in shallower waters than for *Penaeus aztecus* (Fotheringham and Brunenmeister, 1973) and "appears to increase to a single peak and then decline" although the young often seem to have been produced from two or three broods (Lindner and Cook, 1970). The young enter the estuaries in the summer and fall and, as bottom dwellers, utilize many of the same marshes as nurseries previously inhabited by juvenile brown shrimp (TPWD, 1975c). Because of their preference for low salinities, <10 ppt (Cook and Lindner, 1970), these juvenile shrimp seek out the back bays and bayous instead of the marsh areas of the primary bays (TPWD, 1975c). Migrations from the estuaries to the open Gulf are "associated with increasing maturity, intensified by falling temperatures in the latter part of the year" (Lindner and Cook, 1970). Offshore movements generally exhibit a northward trend in late winter and early spring and a southward trend during the fall and early winter (TPWD, 1975f).

PINK SHRIMP - *Penaeus duorarum*

Habitat preferences for the pink shrimp have been described as "estuaries and inner oceanic littoral, predominantly on sand, shell-sand or coral-mud bottom from water's edge to twenty-eight fathoms", rarely deeper (TPWD, 1975f). Spawning seems to be a year-round phenomenon although it increases during the spring, summer and fall and seems to be induced by rising temperatures (Farfante, 1969). The young move to inshore waters and usually arrive at the estuarine nursery grounds as post-larvae (Farfante, 1969). The commercial value of the pink shrimp is less than that of the brown or white shrimp simply because it is less abundant along the Texas coast (TPWD, 1975f).

BLUE CRAB - *Callinectes sapidus*

The blue crab is found over a variety of bottom types although it seems to prefer a substrate of mud and sand (TPWD 1975a; TPWD 1975f). It is most common inshore due to its preference for brackish waters (McEachron, 1977) but can be found as deep as eighteen fathoms (Hildebrand, 1954). The young have a tendency to inhabit lower salinity waters than the adults (Gunter, 1950) and, in fact, blue crab populations are deleteriously affected when freshwater inflow into a particular estuary is decreased (TPWD, 1975a). Spawning generally takes place in the deeper waters of the Gulf (TPWD, 1975f). Eggs are carried by the females until hatching takes place. This occurs "in the Gulf, or occasionally in the bays" (TPWD, 1975f). The blue crab is not only important as the basis for sport crabbing, but also accounts for the "fourth most commercially important fishery along the Texas coast" (TPWD, 1975f).

Alopias vulpinus - thresher shark
Aprionodon isodon - finetooth shark
Carcharhinus acronotus - blacknose shark
Carcharhinus falciformis - silky shark
Carcharhinus leucas - bull shark
Carcharhinus limbatus - blacktip shark
Carcharhinus longimanus - oceanic whitetip shark
Carcharhinus maculipinnis - spinner shark
Carcharhinus obscurus - dusky shark
Carcharhinus porosus - smalltail shark
Galeocerdo cuvieri - tiger shark
Mustelus canis - smooth dogfish
Negaprion brevirostris - lemon shark
Rhizoprionodon terraenovae - Atlantic sharpnose shark
Carcharodon carcharias - white shark
Isurus oxyrinchus - shortfin mako
Odontaspis taurus - sand tiger
Ginglymostoma cirratum - nurse shark
Rhincodon typus - whale shark
Scyliorhinus retifer - chain dogfish
Sphyrna lewini - scalloped hammerhead
Sphyrna mokarran - great hammerhead
Sphyrna tiburo - bonnethead
Sphyrna tudes - smalleye hammerhead
Etmopterus schultzi
Etmopterus virens
Squalus cubensis - Cuban dogfish
Squatina dumerili - Atlantic angel shark
Dasyatis americana - southern stingray
Dasyatis centroura - roughtail stingray
Dasyatis sabina - Atlantic stingray
Dasyatis sayi - bluntnose stingray
Gymnura micrura - smooth butterfly ray
Manta birostris - Atlantic manta
Aetobatus narinari - spotted eagle ray
Myliobatis freminvillei - bullnose ray
Rhinoptera bonasus - cownose ray
Pristis pectinata - smalltooth sawfish
Pristis perotteti - largetooth sawfish
Breviraja sinusmexicana - short-nosed skate
Raja eglanteria - clearnose skate
Raja lentiginosa - freckled skate
Raja olseni - spreadfin skate
Raja texana - roundel skate
Springeria folirostris
Rhinobatos lentiginosus - Atlantic guitarfish
Narcine brasiliensis - lesser electric ray
Hydrolagus alberti - Gulf ratfish
Lepisosteus oculatus - spotted gar
Lepisosteus osseus - longnose gar
Lepisosteus spatula - alligator gar
Lepisosteus spp.
Albula vulpes - bonefish
Elops saurus - ladyfish
Megalops atlantica - tarpon
Anguilla rostrata - American eel
Ariosoma sp.
Conger oceanicus - conger eel
Congrina dubius
Congrina flava - yellow conger
Congrina gracilior - whiptail conger
Neoconger mucronatus - slender pike eel
Paraconger caudilimbatus - margintail conger
Promyllantor schmitti
Uroconger syringus
Dysomma aphododera - shortbelly eel
Moringua edwardsi - spaghetti eel
Hoplunnis macrurus - silver conger
Hoplunnis tenuis - slender pike conger
Enchelycore sp. - chestnut moray
Gymnothorax ocellatus - ocellated moray
Gymnothorax vicinus - purplemouth moray
Bascanichthys scuticaris - whip eel
Echiophis intertinctus - spotted spoon-nose eel
Echiophis mordax - snapper eel
Echiophis punctifer - stippled spoon-nose eel
Letharchus velifer - sailfin eel
Myrophis punctatus - speckled worm eel
Ophichthus gomesi - shrimp eel
Ophichthus ocellatus - palespotted eel
Alosa chrysochloris - skipjack herring
Brevoortia gunteri - finescale menhaden
Brevoortia patronus - gulf menhaden
Brevoortia tyrannus - Atlantic menhaden
Brevoortia spp.
Dorosoma cepedianum - gizzard shad
Dorosoma petenense - threadfin shad
Etrumeus teres - round herring
Harengula pensacolae - scaled sardine
Opisthonema oglinum - Atlantic thread herring
Sardinella anchovia - Spanish sardine
Sardinella sp.
Anchoa hepsetus - striped anchovy
Anchoa mitchilli - bay anchovy
Anchoa nasuta - longnose anchovy
Anchoa sp.
Anchoviella sp.
Engraulis eurystole - silver anchovy
Hiodon alosoides - goldeye
Leptoderma macrops
Argentina silus - Atlantic argentine
Argentina striata
Astronesthes gemmifer
Chauliodus sloani - viperfish
Esox americanus - redfin pickerel
Esox lucius - northern pike
Gonostoma elongata
Yarrella blackfordi
Photostomias guernei
Echiostoma margarita
Argyropelecus aculeatus
Argyropelecus affinis
Argyropelecus gigas
Argyropelecus hemigymnus
Argyropelecus lynchus lynchus
Argyropelecus olfersi
Polyipnus asteroides
Sternoptyx diaphana
Chlorophthalmus agassizi - shortnose greeneye
Chlorophthalmus chalybeius
Parasudis truculenta - longnose greeneye
Diaphus dumerili
Diaphus intermedius
Lampanyctus supralateralis
Myctophum affine
Saurida brasiliensis - largescale lizardfish
Saurida sp.
Synodus foetens - inshore lizardfish
Synodus poeyi - offshore lizardfish
Synodus synodus - red lizardfish
Synodus sp.
Trachinocephalus myops - snakefish
Ictiobus bubalus - smallmouth buffalo
Arius felis - sea catfish
Bagre marinus - gafftopsail catfish
Ictalurus furcatus - blue catfish
Ictalurus melas - black bullhead
Ictalurus natalis - yellow bullhead
Opsanus beta - gulf toadfish
Opsanus pardus - leopard toadfish
Opsanus spp.
Porichthys porosissimus - Atlantic midshipman
Gobiesox punctulatus - stippled clingfish
Gobiesox strumosus - skilletfish
Antennarius ocellatus - ocellated frogfish
Antennarius radiosus - singlespot frogfish
Antennarius scaber - splitlure frogfish
Antennarius sp.
Histrio histrio - sargassumfish
Lophiomus sp.
Dibranchus atlanticus
Halieutichthys aculeatus - pancake batfish
Ogcocephalus nasutus - shortnose batfish
Ogcocephalus parvus - roughback batfish
Ogcocephalus radiatus - polka-dot batfish
Ogcocephalus spp.
Zalieutes mcgintyi - tricorn batfish
Bregmaceros atlanticus - antenna codlet
Gadella maraldi
Merluccius magnoculus - silver hake
Physiculus fulvus
Steindachneria argentea - luminous hake
Urophycis cirratus - gulf hake
Urophycis floridanus - southern hake
Urophycis sp.
Bathygadus macrops
Bathygadus taillanti
Cariburus zaniophorus
Coelorhynchus caribbaeus
Coelorhynchus carminatus
Hymenocephalus cavernosus
Malacocephalus occidentalis
Nezumia bairdi - marlin-spike
Nezumia hildebrandi
Brotula barbata - bearded brotula
Dicrolene intronigra
Gunterichthys longipenis - gold brotula
Lepophidium graellsi - blackedge cusk-eel

Lepophidium sp.
Neobythites gillii
Neobythites marginatus
Ogilbia sp.
Ophidion grayi - blotched cusk-eel
Ophidion holbrooki - bank cusk-eel
Ophidion welshi - crested cusk-eel
Ophidion spp.
Rissola marginata - striped cusk-eel
Membras martinica - rough silverside
Membras sp.
Menidia beryllina - tidewater silverside
Ablennes hians - flat needlefish
Platybelone argalus - keeltail needlefish
Strongylura marina - Atlantic needlefish
Strongylura notata - redfin needlefish
Strongylura sp.
Tylosurus crocodilus - houndfish
Adinia xenica - diamond killifish
Cyprinodon variegatus - sheepshead minnow
Fundulus grandis - gulf killifish
Fundulus pulvereus - bayou killifish
Fundulus similis - longnose killifish
Lucania parva - rainwater killifish
Cypselurus cyanopterus - margined flyingfish
Cypselurus exsiliens - bandwing flyingfish
Cypselurus melanurus - flyingfish
Cypselurus sp.
Euleptorhamphus velox - flying halfbeak
Hirundichthys rondeleti - blackwing flyingfish
Hyporhamphus unifasciatus - halfbeak
Parexocoetus brachypterus - sailfin flyingfish
Gambusia affinis - mosquitofish
Poecilia latipinna - sailfin molly
Barbourisa rufa
Holocentrus ascensionis - squirrelfish
Holocentrus poco - saddle squirrelfish
Holocentrus rufus - longspine squirrelfish
Holocentrus vexillarius - dusky squirrelfish
Polymixia lowei - beardfish
Hoplostethus mediterraneus
Antigonia capros - deepbody boarfish
Cyttopsis roseus
Zenion hololepis
Zenopsis ocellata - American john dory
Aulostomus maculatus - trumpetfish
Macrorhamphosus gracilis - slender snipefish
Macrorhamphosus scolopax - longspine snipefish
Fistularia tabacaria - bluespotted cornetfish
Hippocampus erectus - lined seahorse
Hippocampus obtuses
Hippocampus zosterae - dwarf seahorse
Hippocampus sp.
Syngnathus elucens - shortfin pipefish
Syngnathus floridae - dusky pipefish
Syngnathus fuscus - northern pipefish
Syngnathus louisianae - chain pipefish
Syngnathus pelagicus - sargassum pipefish
Syngnathus scovelli - gulf pipefish
Sygnathus sp.
Acanthurus bahianus - ocean surgeon
Acanthurus chirurgus - doctorfish
Acanthurus coeruleus - blue tang
Apogon aurolineatus - bridle cardinalfish
Apogon maculatus - flamefish
Apogon pseudomaculatus - twospot cardinalfish
Apogon townsendi - belted cardinalfish
Epigonus pandionis
Synagrops bella - blackmouth cardinalfish
Synagrops spinosa
Blennius cristatus - molly miller
Blennius marmoreus - seaweed blenny
Chasmodes bosquianus - striped blenny
Hypleurochilus geminatus - crested blenny
Hypsoblennius ionthas - freckled blenny
Ophioblennius atlanticus - redlip blenny
Caulolatilis cyanops - blackline tilefish
Caulolatilis intermedius - Gulf bar-eyed tilefish
Caulolatilus microps - gray tilefish
Lopholatilus chamaeleonticeps - tilefish
Malacanthus plumieri - sand tilefish
Alectis crinitus - African pompano
Caranx bartholomaei - yellow jack
Caranx hippos - crevalle jack
Caranx latus - horse-eye jack
Caranx ruber - bar jack
Chloroscombrus chrysurus - Atlantic bumper
Elagatis bipinnulata - rainbow runner
Hemicaranx amblyrhynchus - bluntnose jack
Naucrates ductor - pilot fish
Oligoplites saurus - leatherjacket
Selar crumenophthalmus - bigeye scad
Selene vomer - lookdown
Seriola dumerili - greater amberjack
Seriola rivoliana - almaco jack
Seriola zonata - banded rudderfish
Trachinotus carolinus - Florida pompano
Trachinotus crocodilus
Trachinotus falcatus - permit
Trachinotus goodei - palometa
Trachinotus sp.
Trachurus lathami - rough scad
Uraspis secunda - cottonmouth jack
Vomer setapinnis - Atlantic moonfish
Gyrinomimus simplex
Lepomis gulosus - warmouth
Micropterus salmoides - largemouth bass
Pomoxis annularis - white crappie
Pomoxis nigromaculatus - black crappie
Centropomus undecimalis - snook
Centropyge argi - cherubfish
Chaetodon aculeatus - longsnout butterflyfish
Chaetodon aya - bank butterflyfish
Chaetodon capistratus - foureye butterflyfish
Chaetodon ocellatus - spotfin butterflyfish
Chaetodon sendentarius - reef butterflyfish
Chaetodon striatus - banded butterflyfish
Holacanthus bermudensis - blue angelfish
Holacanthus ciliaris - queen angelfish
Holacanthus tricolor - rock beauty
Pomacanthus arcuatus - gray angelfish
Pomacanthus paru - French angelfish
Amblycirrhitus pinos - redspotted hawkfish
Emblemaria pandionis - sailfin blenny
Labrisomus nuchipinnis - hairy blenny
Starksia ocellata - checkered blenny
Coryphaena equisetis - pompano dolphin
Coryphaena hippurus - dolphin
Coryphaena sp.
Echeneis naucrates - sharksucker
Remora australis - whalesucker
Remora osteochir - marlinsucker
Remora remora - remora
Dormitator maculatus - fat sleeper
Eleotris pisonis - spinycheek sleeper
Erotelis smaragdus - emerald sleeper
Gobiomorus dormitor - bigmouth sleeper
Chaetodipterus faber - Atlantic spadefish
Diapterus olisthostomus - Irish pompano
Eucinostomus argenteus - spotfin mojarra
Eucinostomus gula - silver jenny
Eucinostomus spp.
Gerres cinereus - yellowfin mojarra
Ulaema lefroyi - mottled mojarra
Bathygobius soporator - frillfin goby
Bollmannia communis - ragged goby
Coryphopterus punctipectophorus - spotted goby
Evorthodus lyricus - lyre goby
Gnatholepis thompsoni - goldspot goby
Gobioides broussonneti - violet goby
Gobionellus boleosoma - darter goby
Gobionellus hastatus - sharptail goby
Gobionellus oceanicus - highfin goby
Gobionellus shufeldti - freshwater goby
Gobionellus smaragdus - emerald goby
Gobionellus sp.
Gobiosoma bosci - naked goby
Gobiosoma ginsburgi - seaboard goby
Gobiosoma longipala - twoscale goby
Gobiosoma oceanops - neon goby
Gobiosoma robustum - code goby
Gobiosoma sp.
Ioglossus calliurus - blue goby
Lythrypnus nesiotes - island goby
Lythrypnus spilus - bluegold goby
Microgobius gulosus - clown goby
Microgobius thalassinus - green goby
Quisquilius hipoliti - rusty goby
Risor ruber - tusked goby
Rypticus maculatus - whitespotted soapfish
Rypticus saponaceus - greater soapfish
Rypticus subbifrenatus - spotted soapfish
Istiophorus platypterus - sailfish
Makaira nigricans - blue marlin
Tetrapturus albidus - white marlin
Tetrapturus pfluegeri - longbill spearfish
Kyphosus incisor - yellow chub
Kyphosus sectatrix - Bermuda chub

Kyphosus sp. - chub
Bodianus pulchellus - spotfin hogfish
Bodianus rufus - Spanish hogfish
Clepticus parrai - creole wrasse
Halichoeres bivittatus - slippery dick
Halichoeres garnoti
Halichoeres radiatus - pudding wife
Hemipteronotus novacula - pearly razorfish
Lachnolaimus maximus - hogfish
Thalassoma bifasciatum - bluehead
Lobotes surinamensis - tripletail
Lutjanus analis - mutton snapper
Lutjanus apodus - schoolmaster
Lutjanus campechanus - red snapper
Lutjanus cyanopterus - cubera snapper
Lutjanus griseus - gray snapper
Lutjanus synagris - lane snapper
Ocyurus chrysurus - yellowtail snapper
Pristipomoides aquilonaris - wenchman
Rhomboplites aurorubens - vermilion snapper
Microdesmus longipinnis - pink wormfish
Microdesmus sp.
Agonostomus monticola - mountain mullet
Mugil cephalus - striped mullet
Mugil curema - white mullet
Mugil sp.
Mulloidichthys martinicus - yellow goatfish
Pseudupeneus maculatus - spotted goatfish
Upeneus parvus - dwarf goatfish
Lonchopisthus lindneri - swordtail jawfish
Bembrops anatirostris - duckbill flathead
Bembrops gobioides - goby flathead
Polydactylus octonemus - Atlantic threadfin
Abudefduf saxatilis - sergeant major
Abudefduf taurus - night sergeant
Chromis cyanea - blue chromis
Chromis enchrysura - yellowtail reeffish
Chromis insolatus - sunshinefish
Chromis multilineatus - brown chromis
Chromis scotti - purple reeffish
Microspathodon chrysurus - yellowtail damselfish
Pomacentrus dorsopunicans - dusky damselfish
Pomacentrus fuscus - dusky damselfish
Pomacentrus leucostictus - beaugregory
Pomacentrus partitus - bicolor damselfish
Pomacentrus planifrons - yellow damselfish
Pomacentrus variabilis - cocoa damselfish
Anisotremus surinamensis - black margate
Anisotremus virginicus - porkfish
Conodon nobilis - barred grunt
Haemulon aurolineatum - tomtate
Haemulon macrostomum - Spanish grunt
Haemulon melanurum - cottonwick
Haemulon parrai - sailors choice
Haemulon striatum - striped grunt
Orthopristis chrysoptera - pigfish
Pomadasys crocro - burro grunt
Pomatomus saltatrix - bluefish
Priacanthus arenatus - bigeye
Priacanthus cruentatus - glasseye snapper
Pseudopriacanthus altus - short bigeye
Rachycentron canadum - cobia
Scarus taeniopterus - princess parrotfish
Scarus vetula - queen parrotfish
Sparisoma aurofrenatum - redband parrotfish
Sparisoma radians - bucktooth parrotfish
Sparisoma viride - stoplight parrotfish
Bairdiella chrysura - silver perch
Cynoscion arenarius - sand seatrout
Cynoscion nebulosus - spotted seatrout
Cynoscion nothus - silver seatrout
Cynoscion sp.
Equetus lanceolatus - jackknife fish
Equetus umbrosus - cubbyu
Larimus fasciatus - banded drum
Leiostomus xanthurus - spot
Menticirrhus americanus - southern kingfish
Menticirrhus littoralis - gulf kingfish
Menticirrhus saxatalis - northern kingfish
Menticirrhus sp.
Micropogon undulatus - Atlantic croaker
Odontoscion dentex - reef croaker
Pogonias cromis - black drum
Sciaenops ocellata - red drum
Stellifer lanceolatus - star drum
Umbrina coroides - sand drum
Acanthocybium solanderi - wahoo
Auxis thazard - frigate mackerel
Euthynnus alletteratus - little tunny
Euthynnus pelamis - skipjack tuna
Sarda sarda - Atlantic bonito
Scomber japonicus - chub mackerel
Scomberomorus cavalla - king mackerel
Scomberomorus maculatus - Spanish mackerel
Scomberomorus regalis - cero
Thunnus atlanticus - blackfin
Thunnus thynnus - bluefin tuna
Neomerinthe hemingwayi - spinycheek scorpionfish
Pontinus longispinis - longspine scorpionfish
Scorpaena brasiliensis - barbfish
Scorpaena calcarata - smoothhead scorpionfish
Scorpaena dispar - hunchback scorpionfish
Scorpaena plumieri - spotted scorpionfish
Scorpaenodes caribbaeus - reef scorpionfish
Setarches parmatus
Centropristis ocyurus - bank sea bass
Centropristis philadelphica - rock sea bass
Diplectrum bivittatum - dwarf sand perch
Diplectrum formosum - sand perch
Epinephelus adscensionis - rock hind
Epinephelus cruentatus - graysby
Epinephelus drummondhayi - speckled hind
Epinephelus flavolimbatus - yellowedge grouper
Epinephelus guttatus - red hind
Epinephelus inermis - marbled grouper
Epinephelus itajara - jewfish
Epinephelus morio - red grouper
Epinephelus nigritis - Warsaw grouper
Epinephelus niveatus - snowy grouper
Gonioplectrus hispanus - Spanish flag
Hemanthias leptus - longtail bass
Hemanthias vivanus - red barbier
Hypoplectrus chlorurus - yellowtail hamlet
Hypoplectrus unicolor - butter hamlet
Liopropoma eukrines - wrasse bass
Liopropoma rubre - peppermint bass
Morone saxatilis - striped bass
Mycteroperca bonaci - black grouper
Mycteroperca interstitialis - yellowmouth grouper
Mycteroperca microlepis - gag
Mycteroperca phenax - scamp
Mycteroperca rubra - comb grouper
Mycteroperca sp.
Paranthias furcifer - creole-fish
Pikea mexicana - yellowtail bass
Serraniculus pumilio - pygmy sea bass
Serranus atrobranchus - blackear bass
Serranus phoebe - tattler
Serranus subligarius - belted sandfish
Archosargus probatocephalus - sheepshead
Calamus arctifrons - grass porgy
Calamus bajonado - jolthead porgy
Calamus calamus - saucereye porgy
Calamus campechanus - Campeche porgy
Calamus leucosteus - whitebone porgy
Calamus nodosus - knobbed porgy
Calamus penna - sheepshead porgy
Calamus sp.
Diplodus holbrooki - spottail pinfish
Lagodon rhomboides - pinfish
Stenotomus caprinus - longspine porgy
Sphyraena barracuda - great barracuda
Sphyraena borealis - northern sennet
Sphyraena guachancho - guaguanche
Ariomma bondi - silver-rag
Centrolophus niger - black ruff
Hyperoglyphe bythites
Nomeus gronovii - man-of-war fish
Peprilus alepidotus - harvestfish
Peprilus burti - gulf butterfish
Peprilus simillimus - Pacific pompano
Psenes pellucidus - blackrag
Trichiuris lepturus - Atlantic cutlassfish
Bellator militaris - horned searobin
Peristedion longispathum
Peristedion miniatum - armored searobin
Peristedion gracile - slender searobin
Prionotus evolans - striped searobin
Prionotus martis - barred searobin
Prionotus ophryas - bandtail searobin
Prionotus paralatus - Mexican searobin
Prionotus roseus - bluespotted searobin
Prionotus rubio - blackfin searobin
Prionotus salmonicolor - blackwing searobin
Prionotus scitulus - leopard searobin
Prionotus stearnsi - shortwing searobin
Prionotus tribulus - bighead searobin
Prionotus sp.

Astroscopus y-graecum - southern stargazer
Gnathagnus egregius - freckled stargazer
Kathetostoma albigutta - lancer stargazer
Xiphias gladius - swordfish
Ancylopsetta dilecta - three-eye flounder
Ancylopsetta quadrocellata - ocellated flounder
Bothus spp.
Citharichthys cornutus - horned whiff
Citharichthys macrops - spotted whiff
Citharichthys spilopterus - bay whiff
Citharichthys sp.
Cyclopsetta chittendeni - Mexican flounder
Cyclopsetta fimbriata - spotfin flounder
Engyophrys senta - spiny flounder
Etropus crossotus - fringed flounder
Etropus sp.
Monolene sessilicauda - deepwater flounder
Paralichthys albigutta - gulf flounder
Paralichthys lethostigma - southern flounder
Paralichthys squamilentus - broad flounder
Paralichthys sp.
Syacium gunteri - shoal flounder
Syacium papillosum - dusky flounder
Trichopsetta ventralis - sash flounder
Symphurus civitatus - offshore tonguefish
Symphurus diomedianus - spottedfin tonguefish
Symphurus parvus - pygmy tonguefish
Symphurus pelicanus - longtail tonguefish
Symphurus piger - deepwater tonguefish
Symphurus plagiusa - blackcheek tonguefish
Symphurus sp.
Poecilopsetta beani
Achirus lineatus - lined sole
Gymnachirus texae - fringed sole
Trinectes maculatus - hogchoker
Aluterus heudeloti - dotterel filefish
Aluterus schoepfi - orange filefish
Aluterus scriptus - scrawled filefish
Balistes capriscus - gray triggerfish
Balistes vetula - queen triggerfish
Canthidermis sufflamen - ocean triggerfish
Cantherhines pullus - orangespotted filefish
Melichthys niger - black durgon
Monacanthus ciliatus - fringed filefish
Monacanthus hispidus - planehead filefish
Monacanthus setifer - pygmy filefish
Xanthichthys ringens - sargassum triggerfish
Chilomycterus schoepfi - striped burrfish
Diodon holocanthus - balloonfish
Diodon hystrix - porcupinefish
Mola lanceolata - sharptail mola
Mola mola - ocean sunfish
Lactophrys quadricornis - scrawled cowfish
Lactophrys trigonus - trunkfish
Lactophrys triqueter - smooth trunkfish
Lactophrys sp.
Canthigaster rostrata - sharpnose puffer
Lagocephalus laevigatus - smooth puffer
Sphoeroides dorsalis - marbled puffer
Sphoeroides nephelus - southern puffer
Sphoeroides pachygaster - blunthead puffer
Sphoeroides parvus - least puffer
Sphoeroides spengleri - bandtail puffer
Sphoeroides testudineus - checkered puffer
Sphoeroides sp.
Parahollardia lineata - jambeau

TABLE I

COMMERCIAL FISH LANDINGS

Yearly Mean for Six Year Period

(September 1972 - August 1978)

	Gulf Landings		Bay Landings	
Fish	Mean Pounds	Mean Value	Mean Pounds	Mean Value
Pompano	1,712	$ 1,049	3,108	$ 1,487
Red Snapper	606,868	396,652	*1,587	*1,319
Mullet	33,982	2,230	37,589	2,904
White Seatrout	1,974	671	13,967	4,466
Spotted Seatrout	244,792	94,750	1,448,911	597,614
Croaker	31,070	2,401	67,528	5,845
Blackdrum	65,303	9,774	1,431,923	316,855
Redfish	92,916	33,632	1,517,116	597,989
Sheepshead	48,075	5,823	273,008	24,382
Flounder	224,733	70,300	185,219	82,081
American Eastern Oyster	--	--	2,566,731	2,238,621
Squid	7,191	1,663	5,142	1,260
Brown and Pink Shrimp	58,641,732	75,839,846	3,966,214	1,629,653
White Shrimp	*10,307,259	*13,778,960	7,124,062	5,950,077
Blue Crab	47,739	5,987	6,736,685	1,204,318

* yearly mean for less than six year period

EFFECTS OF OIL ON BIOLOGICAL SYSTEMS

Introduction

Oil pollution of the sea from various sources is fast becoming a serious global problem. Oil pollution does not respect any national boundaries--nor are its effects easy to predict. Some marine life seems almost unaffected by oil, but under other conditions oil is lethal to a variety of species.

Research on the effects of oil on living organisms has been performed in the laboratory since the beginning of the century, but most of the early research lacked adequate controls, or description of the oil or oil fractions used. Other conclusions concerning the effects of oil on marine life have been drawn from studies of oil spills in the past. A great deal of enlightenment has been obtained from studies of major spills, such as Santa Barbara and Amoco Cadiz. This paper summarizes briefly the toxic effects of oil on marine organisms, the factors affecting oil toxicity, and the possible effects of the Ixtoc I oil spill.

Evans and Rice (1974) list eight ways in which oil poses a potential danger to marine life:

(1) Direct kill of organisms through coating and asphyxiation.
(2) Direct kill through contact poisoning of organisms.
(3) Direct kill through exposure to the water-soluble toxic components of oil at some distance in space and time from the accident.
(4) Destruction of the generally more sensitive juvenile forms of organisms.
(5) Destruction of the food sources of higher species.
(6) Incorporation of sublethal amounts of oil and oil products into organisms (resulting in reduced resistance to infection

and other stresses--the principal cause of death in birds surviving immediate exposure to oil).

(7) Incorporation of carcinogenic and potentially mutagenic chemicals into marine organisms.

(8) Low-level effects that may interrupt any of numerous events (such as prey location, predator avoidance, mate location or other sexual stimuli, and homing behavior) necessary for the propagation of marine species and for the survival of those species higher in the marine food web.

All of these short-term effects have been documented either in laboratory or field experiments. The long-term effects on marine life of an accumulation of tar from successive spills have not yet made themselves felt.

I. Effects on Marine Organisms

A. Primary Producers

Most of the biomass of the ocean is in the form of one-celled pelagic plants known as phytoplankton. Phytoplankton potentially could be affected severely by oil spills since a large proportion of the phytoplankton is near the surface of the water, where oil concentrates and has its greatest effects. Galtsoff et al. (1935) examined the effect of oil and oil extracts on the diatom *Nitzchia closterium* E. A heavy layer of surface oil left on the surface longer than a week tended to inhibit growth of the diatom. When diatom cultures were treated with oil extracts at a concentration of 25% or higher for a considerable period of time, growth was retarded. Similarly, Sanborn (1977) found an immediate and complete loss of photosynthesis occurred when the flagellate *Chlamydomonas angulosa* was treated with aqueous extracts. Sanborn concluded that the effects of oil on the species can only be surmised. These results are at odds with recently published studies by Pulich (1979) who found no observable effects of weathered Mexican oil on photosynthesis of cultures of diatoms and green flagellates. Pulich (1979) however warns that the experimental results should not be interpreted to mean that Mexican oil will have no effect on growth and cell division of Gulf of Mexico phytoplankton populations. He points out, for example, that some lethal hydrocarbon compounds had no immediate effect on photosynthesis.

Inshore, grasses are major producers of biomass and provide shelter and food to larvae and adults of a wide variety of species. Marsh grass seems to be especially vulnerable to the toxic coating effect of spilled oil (Roland et al., 1977, Nadeau and Bergquist, 1977). However, marshes and estuarine systems have a high energy flow which may reduce the residence time of the oil in the marsh grass system (Hershner and Moore, 1977). Mangroves also can be severely affected, especially young trees (E. I. Chan, 1977).

At this time, the total effect of spilled oil on marine plant life could only be surmised, even if more complete information was available. Oil probably affects some species more severely than others and individual laboratory testing is needed to determine harmful amounts. For mangroves and sea grass communities to recolonize following a fatal spill should take quite a long time in nature due to changes in the substrate in which they grow and the long generation time of these species. Phytoplankton, on the other hand, should recover fairly quickly due to its immense powers of reproduction.

B. Primary Consumers

1. Zooplankton

The most important group of primary consumers in the Gulf of Mexico is the zooplankton population. There are two important kinds of zooplankton. The first are organisms which remain in the zooplankton their entire lives, such as copepods, amphipods and other small crustaceans. There also are zooplankters which are the eggs and larvae of larger organisms such as fish, molluscs and larger crustaceans. Both kinds of zooplankton feed on phytoplankton and smaller zooplankters.

Descriptions of the general effect of oil on zooplankton of the first kind have sometimes been published, with contradictory results. Sanborn (1977) reported no harmful effects of oil on zooplankton after the Santa Barbara or the Torrey Canyon spills. The University of Texas Marine Science Institute (1977) stated that although hydrocarbon fractions were found in zooplankton tissues, indicating substantial petroleum contamination, there was no observable effect. Sanborn also reported that the ingestion of oil had no effect on zooplankton. In contrast, Galtsoff et al. (1935) reported that Elmhirst in 1922 found that plankton was killed by contact with oil. How Elmhirst performed his experiment is not known.

Several species of planktonic invertebrate larvae have been subjected to oil extracts. Sanborn (1977) reported that some planktonic larvae of benthic invertebrates are killed by contact with oil pollution. In particular, the gametes of these invertebrates, which are released into the water, are extremely sensitive. The larvae in an oil polluted area during the period of the spill could experience possible mortality through eutrophication of the water, change in the sediment on which they would settle, direct poisoning, or the disappearance of gregarious settled larvae followed by failure to recolonize (Sanborn, 1977).

Larvae and eggs of fishes have also been exposed to oil. Sanborn (1977) says that pilchard eggs showed high mortality in the Torrey Canyon spill. Also, developing eggs of the Black Sea flatfish, *Rhombus maesticus*, were highly sensitive to oil and oil products down to a concentration of 10^{-5}ml/liter. Hatched larvae were more resistant. On the Texas coast, Arnold et al. (1979) found that redfish (*Sciaenops ocellata*) larvae and eggs both experienced mortality and developmental abnormalities when exposed to water soluble fractions of oil. As with the plant life, the effect of oil on the zooplankton probably varies with the species. The small planktonic organisms which reproduce rapidly would probably not be long affected by oil pollution, no matter how severe the initial kill. The planktonic larvae and eggs, which seem more susceptible to oil pollution on the weight of the data, would also be more severely affected due to their much longer generation time.

2. Benthic Invertebrates

a. Oyster

The American eastern oyster, *Crassostrea virginica*, has been one of the most widely used organisms for oil spill studies. The species is widely used for food, but oil pollution gives oysters an oily taste, making them unmarketable (Galtsoff et al., 1935; St. Amant, 1970), and therefore research on this species has been stimulated. Also, the filter-feeding mechanism of the oyster raises the question of what happens to an organism that strains oil from the water along with its food. Oysters also make good subjects for experiments because of their sedentary habits, which make large tanks unnecessary.

Other effects on oysters of natural oil spills have been categorized as mortality, tarry coating on the shells, watery color and texture, reduced glycogen content, and reduction of gonad development (Galtsoff et al., 1935).

Weathered oil sinks to the bottom and when released by storms, oyster harvesting or dredging, continues to have the same effects (Galtsoff et al., 1935).

Laboratory experiments on oysters show that they are not greatly affected by oil in seawater unless the water is stagnant (Galtsoff et al., 1935). Lund (1957) measured the ability of oysters to clear water of food particles and found that high concentrations of bleedwater, greater than 15%, slowed the ability of the oysters to clear the water. Soluble oil fractions and crude oil at low concentrations had no effect on the oyster's ability to clear the water or take in suspended matter.

Oysters can protect themselves from large doses of oil in water by closing their valves tight and excluding water from their shells. Varanasi and Malins (1977) found that oysters remained closed when there was 900 mg/liter crude oil in the water. Oysters, like many other marine species, can also remove assimilated hydrocarbons from their tissues once the oil has disappeared from the water.

The weight of the data indicates that while oil has potentially severe effects on oysters, an oil spill, with diluted and weathered oil, will not result in serious mortality in the oyster population. A large spill directly on the reef would probably result in serious loss. However, even small spills may lower the oyster's commercial value by affecting its taste, and little is known about the effects of oil on the ability of oyster larvae to settle. While the adult oysters can protect themselves from oil by closing their valves, the spat are more vulnerable to oil, especially oil on the rocks where they are to settle (Sanborn, 1977).

b. Other Molluscs and Annellid Worms

Benthic invertebrates, such as other mollusks beside oysters, and annellid worms are severely affected by settlement of oil on the substrate (Sanborn, 1977). Those organisms which are filter-feeders may have their gills or filter mechanisms clogged by oil or tar particles, smothering the animal. This danger is greatest for those benthic organisms which live in the subtidal or intertidal zones, near the shore, where oil is most likely to be washed up.

In one incident, polychaetes suffered mortalities when cracking residue thinned with Number 2 fuel oil was spilled on the beach (Sanborn, 1977). Benthic worms are especially vulnerable to the smothering effects of oil, even weathered oil. Isopods, small crustaceans which are important scavengers, are trapped and killed by oil spilled in the intertidal region (Cubit, 1970). Other benthic organisms below the high tide mark are likely to suffer the same fate. Other effects on benthic animals may stem from alteration of the substrate rather than asphyxiation or coating. For example, the polychaete bloodworm *Euzonus mucronata* usually burrows to the top of the sand during receding tides. When the sand was coated with spilled oil the worms avoided the surface (Cubit, 1970).

Oil in the sediment affects molluscs, such as clams. For instance, large numbers of Pismo clams, *Tivela stultorum*, and razor clams, *Siligua patula*, were killed by spills of diesel oil in California (Sanborn, 1977). Here only the initial kill was reported, but oil in sediments may result in continuing mortality. A serious spill of No. 2

fuel oil mixed with JP5 jet fuel in Searsport, Maine caused continued mortality of clams of the genus *Mya*, with 85% of the harvestable population killed in 3 years. The estimated loss was 50 million clams. The surviving clams had a high incidence of gonadal tumors which in some cases replaced gonadal tissue. Note that this spill involved refined products which would be expected to be more dangerous to marine life, due to their lower molecular weight (Sanborn, 1977). Further evidence of the tendency of hydrocarbons to remain in the sediment is provided by a spill of crude oil in Casco Bay, Maine, where the clams still showed contamination nine years after the spill (Sanborn, 1977).

3. Fishes

Two common species of fish, the striped mullet, *Mugil cephalus* L. and the Atlantic menhaden, *Brevoortia patronus*, can be considered primary consumers, as they feed mostly on the plankton. Adult fishes are presumably more able to avoid oil spills than other marine species since their mobility is greater. Thus one would expect fish species to make contact with oil mainly in the act of feeding upon oiled food items. Fishes which filter small items out of the water in the act of feeding would seemingly be more likely to ingest oil than those which eat larger items. St. Amant (1970) states that menhaden are not affected by oil pollution, although he notes that fishes that have fed upon oily food develop an oily taste. More information is needed on these species, which are important members of the food web.

C. Secondary Consumers

1. Shrimp

Gulf shrimp of the genus *Penaeus* are an important part of the food chain. They feed on smaller crustaceans and plankton of all sorts, and are a preferred food of all the larger fish species. Man also prefers these shrimp, known as white, brown, and pink shrimp, as an item of his diet.

Shrimp, being partly filter-feeders, are susceptible to ingesting oil or tar particles, or becoming entangled in oil. A recent study by Flint et al. (1979) found slight mortality (9%) at the highest concentration of oil accommodated water, and less mortality at lower concentrations. This shows that besides the clogging effect on gills of oil particles, shrimp are affected by direct toxicity of oil. As with all the organisms that have planktonic larval stages, the possibility that the larvae may be more severely affected than the adults cannot be ignored (Evans and Rice, 1974).

2. Fishes

Sanborn (1977) lists 5 possible ways in which an oil spill can cause damage to fish populations: First, egg and larval mortality by direct coating or toxic effects, (2) Adults could be killed in a similar way in narrow or shallow water, (3) Contamination of spawning grounds, (4) Fecundity or spawning behavior may change, and (5) Local food species may be adversely affected.

In a study of fishes of "oiled" and "nonoiled" environments, Ebeling et al. (1970) found no significant difference between them. St. Amant in 1970 reported that commercial fishes faced with chronic oil pollution have not experienced any serious breakdown in the food chain or animal life cycles. Nevertheless, he recognized that finfishes which feed on lower forms which have ingested oil develop an unpleasant oily taste which could affect their market value (St. Amant, 1970). More serious than the oily taste from ingestion of oil in food, is the fact that fishes also assimilate oil hydrocarbons directly from the water. One experiment, cited in Galtsoff et al. (1935), found that an extract prepared by shaking 100cc of oil with 2,000cc of distilled water was toxic to brown trout.

Young and larval fishes are generally more adversely affected by oil pollution (Craddock, 1971). This has been observed in larvae of plaice and flounders (Galtsoff et al., 1935), and pilchard eggs and eggs of Black Sea flatfishes (Sanborn, 1977). Arnold et al. (1979) found a very definite statistical relationship: as the concentration of oil in water rose, the number of fish eggs and larvae which were deformed or dead also rose. Although from the foregoing experiments it appears that small larvae are sensitive to oil, one set of experiments seems to indicate the reverse. Gardinier (1927), cited in Galtsoff et al. (1935), reported that trout when only 60 days old showed no effects from 2-hour immersion in a 40 phenol:100,000 water solution. The same species, when 110 days old, was unable to withstand a 15-minute immersion. Most early experiments on oil toxicity are suspect because at that time the experimental methodology was not as rigorous as it has become, and the results were often not reported in statistically analyzable form. Modern experiments, such as Arnold et al. (1979), are much more trustworthy.

Studies indicate that the commercial fishery in the Black Sea has been nearly ruined by oil pollution. Sanborn (1977) states that the first sign was a fall in zooplankton productivity. Since 1930, sturgeon catches have dropped to one-third of their former level, and salmon, bream, carp, and sild catch have dropped to one-tenth. The Black Sea is nearly landlocked, Sanborn points out, and oil can't escape or be diluted as in other bodies of water. The chronic oil pollution problem there is very bad. The North and Baltic Seas have also been frequently polluted by spilled oil for decades, but Sanborn reports no effect on the fish population. He attributes this to the better exchange of water between the Baltic Sea, the North Sea and the Atlantic Ocean.

3. Squid

Squid are generalized predators, occupying roughly the same place in the food chain as sport fishes such as the redfish. Squid lay their eggs on the bottom, so one might postulate that their immature stages would not be as susceptible to direct toxic effects as the floating eggs of fishes. No experiments on effects of oil on squid were located in the literature search.

4. Crabs

Crabs are considered secondary consumers because of their appetite for flesh, but much of their food is obtained from scavenging. The blue crab, *Callinectes sapidus*, is abundant over much of the world, and especially common in the Gulf of Mexico. It is the object of a considerable sport and commercial fishery, as crab meat is considered a delicacy.

All the crabs have planktonic larvae, which are vulnerable to floating oil, like other zooplankton. Adult crabs are likely to become exposed to weathered oil or tar when scavenging on or near the bottom. More needs to be known about the effect of oil on the life stages of the blue crab.

5. Birds

A number of migratory and native bird species depend mostly or wholly upon the productivity of the Gulf, bay and estuarine areas of the Texas coast. Birds in general are very vulnerable to spilled oil, which coats their feathers and renders them useless for flying or insulation against cold. Birds attempting to preen oil out of their feathers may then succumb to the toxic effects of petroleum. Oiled seabirds are one of the first obvious effects of an oil spill (Gorman and Simms, 1978). More than 3,450 birds of 33 species were killed by the Amoco Cadiz spill in 1978 and other oil spills have almost invariably taken a large toll (Jones et al., 1978). Mortality continues up to 300 days after the birds' exposure to oil (Cowell, 1976).

Sublethal effects on birds from exposure to spilled oil include enteric respiratory disorders, renal disorders, lung infections, arthritis, and dessication through physiological imbalances and metabolic changes (Cowell, 1976). A good idea of the danger that spilled oil presents to birds can be had from the fact that only 5% of auks, when cleaned and kept in captivity, recover from oil coatings. Gulls and ducks, which adjust better to cleaning, may have a recovery rate of 75% (Cowell, 1976). Gorman and Simms (1978) found that ingested crude oil did not result in slower growth in nestling gulls, as had been earlier reported. This may indicate that ingestion of oil is relatively unimportant, and that most of the bird mortality occurs from oil coating bird plumage.

Although seabirds are appreciated more for their aesthetic value than for any commercial value they might have, their susceptibility to oil should be investigated further, since they are warm-blooded animals like man, and are relatively high in the food chain.

D. Tertiary Consumers

1. Man

Man should be less vulnerable to toxic effects of oil that he ingests in his food, because man is the only animal who exercises rigid quality control over his food. This is in contrast to the behavior of plaice, *Pleuronectes platessa*, which prefer to eat oiled shrimp, since they are caught more easily than healthy ones (Sanborn, 1977).

Oil spills are likely to affect man by removing items from his diet. Not only will contaminated food be unfit for human consumption, but toxic effects may kill off food species thus reducing the efficiency of the fish and shrimp harvesting industry. Low levels of hydrocarbon pollution can result in carcinogenic or mutagenic chemicals in the human diet.

II. Factors Affecting the Toxicity of Oil

A. Chemical Factors

Most damage to wildife is done by the most volatile fractions of oil. There is general agreement that the smaller the hydrocarbon molecule, the greater its toxicity to life. (Cowell, 1976, Moore and Dwyer, 1974). Aromatic hydrocarbons (those molecules containing an aromatic or benzene ring) are more toxic than straight chain or branched ones (Evans and Rice, 1974). Toxicity of molecules increases in the series paraffins, naphthalenes, olefins and aromatics, according to Cowell (1976). Molecules which are more soluble in water pose a greater risk of being assimilated (Cowell, 1976). Most authors therefore state with good reason that the low boiling, more water-soluble aromatics are the primary cause of immediate biological damage.

B. Physical Factors

When exposed to atmospheric conditions, oil tends to break down, a process known as weathering. On a volume basis, oil becomes less toxic to life the longer it weathers (Bender, 1977). Evaporation of the smaller, more volatile molecules is the major weathering process which removes the most toxic molecules from the marine environment. Other hydrocarbons undergo photooxidation, a process in which they are broken down into smaller molecules by solar radiation in the presence of oxygen. Although this process is not as fast as evaporation, it continues to break down the large molecules after the smaller ones have been lost through evaporation.

Burning of the spilled oil, of course, greatly accelerates its removal from the oceanic environment. The constituents most likely to be oxidized by burning are the small molecules and aromatics. This process generates heat which evaporates other oil molecules. Although burning renders the more dangerous components of spilled oil harmless to marine life, the air pollution effects from hydrocarbon smoke on all terrestrial life can be serious.

Oil can be removed from the water by adsorption onto suspended sediments which then settle to the bottom. This was a major factor in carrying much of the spilled oil to the sea floor following the Santa Barbara spill in 1969 (Evans and Rice, 1974).

Physical effects can increase the toxicity of oil as well as decrease it. Mixing of oil with water can cause the more water-soluble components to go into solution more quickly, and cause increased mortality. In one example, intense onshore winds and shallow water caused oil droplets to mix with water which caused sudden mortality in sea cucumbers, conchs, prawns, sea urchins and polychaetes (Nadeau and Bergquist, 1977).

Oil may act synergistically with physical effects with unexpected consequences. An intertidal barnacle, *Pollicipes polymerus*, is prevented from breeding by the presence of oil in the surrounding area. The cessation of reproduction was linked to a rise in body temperature when the black oil absorbed solar heat (Straughan, 1977).

C. Biological Factors

1. Biodegradation

Two ways in which oil can be detoxified (photooxidation and evaporation) have already been mentioned. The third way in which oil becomes less dangerous to organisms is biodegradation. This process involves the entrance of oil hydrocarbons into the tissues of an animal or plant, and the subsequent oxidation of the molecule as part of the organism's metabolism (Gibson, 1977). The most efficient hydrocarbon oxidizers are certain microorganisms including bacteria, filamentous fungi and yeasts (ZoBell, 1973, Yall, 1979).

Each species of microorganism typically only oxidizes a small spectrum of hydrocarbon compounds, because all of them do not possess the necessary enzymes to break down a wider range of compounds. They are very abundant, however. In oil-polluted harbors or oil dumps there may be 10^3 to 10^6 oil-oxidizing microorganisms per milliliter. In bottom sediments the population may reach 10^9 oil-oxidizing microorganisms per milliliter (ZoBell, 1973).

All of the oil-oxidizing organisms in the bottom sediments are near the surface of the sediment because the oil-oxidizing process is aerobic, requiring dissolved oxygen. Oil deposited in deeper sediments therefore is not biodegraded unless it is exposed to dissolved oxygen by wave action or some other disturbance. There is therefore a danger that successive oil spills will build up layers of tar in marine sediments which will be a barrier to burrowing animals (Cubit, 1970). Alternatively, the oil could be ingested and returned to the biosphere by sediment-inhabiting organisms. The oil-laden sediment could therefore become a source of a chronic oil pollution problem in the area where the spill occurred (Evans and Rice, 1974).

Hydrocarbons are known to remain stable in marine sediments for geologically long periods of time. Crude oil is in fact formed from hydrocarbon sediments which are the remains of marine animals and plants. The effect of such sediments on the living organisms in an area declines with the sediment depth, and therefore its age.

2. Incorporation in the Food Web

Hydrocarbons, when spilled in the marine environment, invariably will enter the food chain. Most hydrocarbons are lipid (fat) soluble and therefore tend to accumulate in fatty tissues of animals that ingest them. As animals that are low in the food chain are eaten by ones that are higher, the hydrocarbons spread throughout the fauna in the area of the oil spill.

Oil is most likely to be incorporated into the food chain when it is freshly spilled. At this time, floating oil is absorbed by zooplankton and phytoplankton. The most toxic molecules have not yet evaporated and are still present in the oil-water mixture at this time. Cox et al. (1975) found that the highest concentration of naphthalenes in seawater was approximately 48 hours after the spill. This was the time of greatest mortality and the highest concentration of naphthalenes in animals sampled from the area. Other hydrocarbons were presumably also present in high concentration.

By 14 days after the spill the naphthalenes reached a peak concentration in the sediment (Cox et al., 1975). This is the time when benthic animals, especially detritus feeders such as annelids, are in the greatest danger of feeling the toxic effects of hydrocarbons. As the concentration of oil drops in succeeding weeks, the toxic effects decrease, but the oil may still enter the food chain through the benthic animals; and will continue to do so until it is buried too deep to be ingested.

Like petroleum hydrocarbons, the chlorinated hydrocarbons such as DDT are fat-soluble and accumulate in the fatty tissues of animals (Evans and Rice, 1974). Chlorinated hydrocarbons also are concentrated in the food chain because animals are not able to excrete them and therefore retain nearly all that they have ingested in their life. This results in mortality and sublethal effects, especially at the top of the food chain, where the effects of DDT on the eggshells of predatory birds are well known. It is now known that DDT is more soluble in petroleum hydrocarbons than in water. Consequently DDT concentrates near the surface of the water when oil is present there, exposing surface organisms to a higher concentration of DDT (Ehrlich et al., 1973).

Opinion is divided on whether oil-derived hydrocarbons accumulate in the food chain. Scarratt and Zitko (1972) note that carnivores tend to have lower concentrations of oil than herbivores and conclude that oil most likely is not concentrated in the food chain. Evans and Rice (1974) cite several authorities in support of the theory that certain hydrocarbons may accumulate in the food chain. They also indicate that oil may be excreted in the feces of animals which have ingested it. There are also many references that document the accumulation of hydrocarbons by marine animals living in oil-polluted water, followed by the return of the hydrocarbons to the environment when the water becomes clean (Anderson and Neff, 1974; Fossato and Conzonier, 1976). Some species studied have also shown an ability to partly metabolize assimilated oil hydrocarbons (Scarratt and Zitko, 1972).

Apparently, the biological fate of hydrocarbon molecules depends on the molecule and the organism involved. An animal or plant in an oil-polluted environment has no choice but to absorb oil from the environment or from its food. If the oil is not passed out immediately in the feces, then it seems there are three things which can happen to an assimilated oil molecule.

(1) The molecule is stored in tissue and accumulates; the animal has no enzyme or transport system to get rid of it.
(2) The molecule is metabolized; the animal possesses the enzymes necessary to break it down.
(3) The molecule is transported out of the body; the animal gets rid of the molecule with the waste products of cellular respiration or cellular breakdown.

Some animals may be porous to certain molecules, taking them up and then releasing them. Processes (2) and (3) happen at some rate which may be too slow to guarantee that all the hydrocarbons are actually excreted or metabolized. In that case the molecules are passed up the food chain in the same way as those molecules which are stored in tissue.

A toxic molecule which occurs in the spilled oil at a low concentration may rise in concentration as it goes up the food chain. This process would be the major danger from hydrocarbon molecules which are not metabolized or transported out of the organism. It could cause mortality to predators at the highest trophic level. Eggs or larvae mortality of the predator species could also be threatened, since embryos usually have a lower tolerance to toxic substances (Craddock, 1971).

It should be remembered that some molecules may also have carcinogenic or disabling effects on the organism even if they are only present within its body for a short time. For an exhaustive listing of sublethal effects on various phyla, see Johnson (1974). Such sublethal effects can be caused by persistent concentrations of soluble aromatic derivatives in the range 10-100 parts per billion (Moore and Dwyer, 1974).

III. Toxicity of Ixtoc I Oil

The best available report on the composition of Ixtoc I oil (Parker et al., 1979) indicates that it is not especially different from other crudes. At the well, Ixtoc I crude contained 52-53% saturated hydrocarbons, 34-35% aromatics and 7-8% NSO compounds. Data on Arabian and Iranian oil indicate that the oil spilled from the Amoco Cadiz had between 30 and 35% aromatics and 50-83% paraffins, or saturated hydrocarbons (Spooner, 1978). Toxicity of oil depends first upon its composition, and therefore there is no reason to believe the Ixtoc I oil to be more toxic than, for instance, the Amoco Cadiz oil. Other oil spills, involving fuel oil, gasoline or jet fuel, caused more damage to marine life since the lighter fractions of petroleum are more toxic (Sanborn, 1977).

Ixtoc I oil underwent a considerable amount of weathering before landfall in Texas. Figures 3 and 4 show the composition of Ixtoc I oil forty hours after the spill, and oil collected by the USCG Pt. Baker at 22° 50'N and 96° 26'W. This is a point not reached by the oil until July 24, 51 days after the blowout. The most common constituents of the 40-hour oil are saturated hydrocarbons of fewer than 14 carbons and various naphthalenes, also of low molecular weight. After weathering, these components almost disappear. Saturated hydrocarbons in the 17 to 20 carbon range are the most common, along with higher order aromatic compounds. Thus the first compounds removed by weathering (a term that includes evaporation, photooxidation and biodegradation) are the most common and most toxic to life.

From the distance which Ixtoc I oil had to travel before its landfall on Texas beaches, one must conclude that its most toxic components were probably first removed by weathering. The sheer amount of oil continuing to be spilled indicates that the toxic effects near the well are probably severe indeed. In addition, much of the oil must settle onto sediments not far from the well, making nutrients from the bottom unavailable for much of the marine life in the area. How large an area will be so affected is not known, but if other spills are any indication, it could be several years after the flow is stopped before newly deposited bottom sediments again support a variety of marine life (Moore and Dwyer, 1974).

Recent reports by the Texas Department of Health Resources indicate that so far fishes and shrimps from Texas waters are not being contaminated by Ixtoc I oil (Munoz and Sherry, 1979). Continued sampling over a wide area will provide valuable information on the movement and persistence of oil molecules in biological systems.

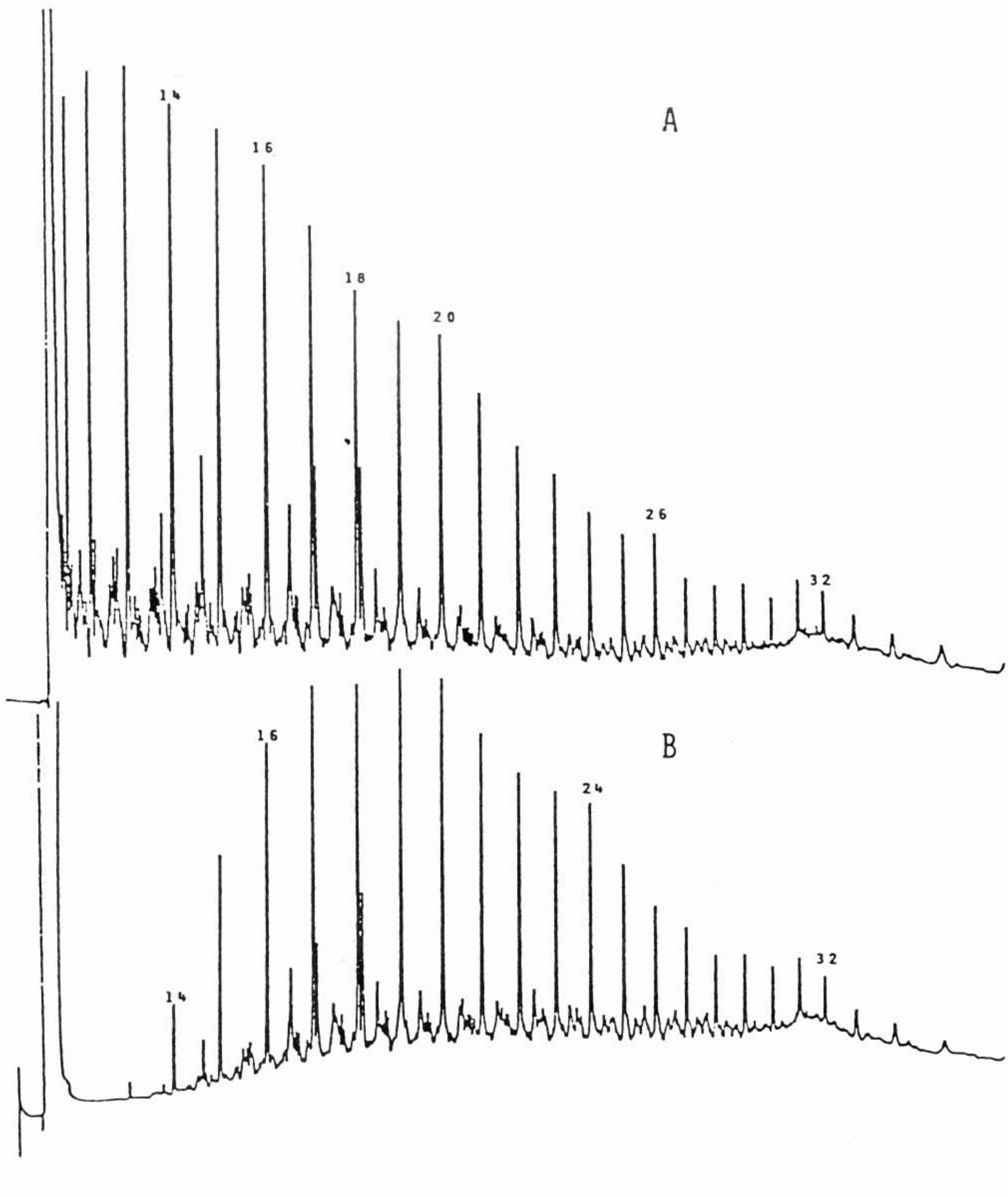


Figure 3. Gas chromatograms of the saturate fraction of a mousse sample collected 40 hrs after the IXTOC I blowout (A), and the Pt. Baker mousse (B). (Figure from Parker et al., [1979]).

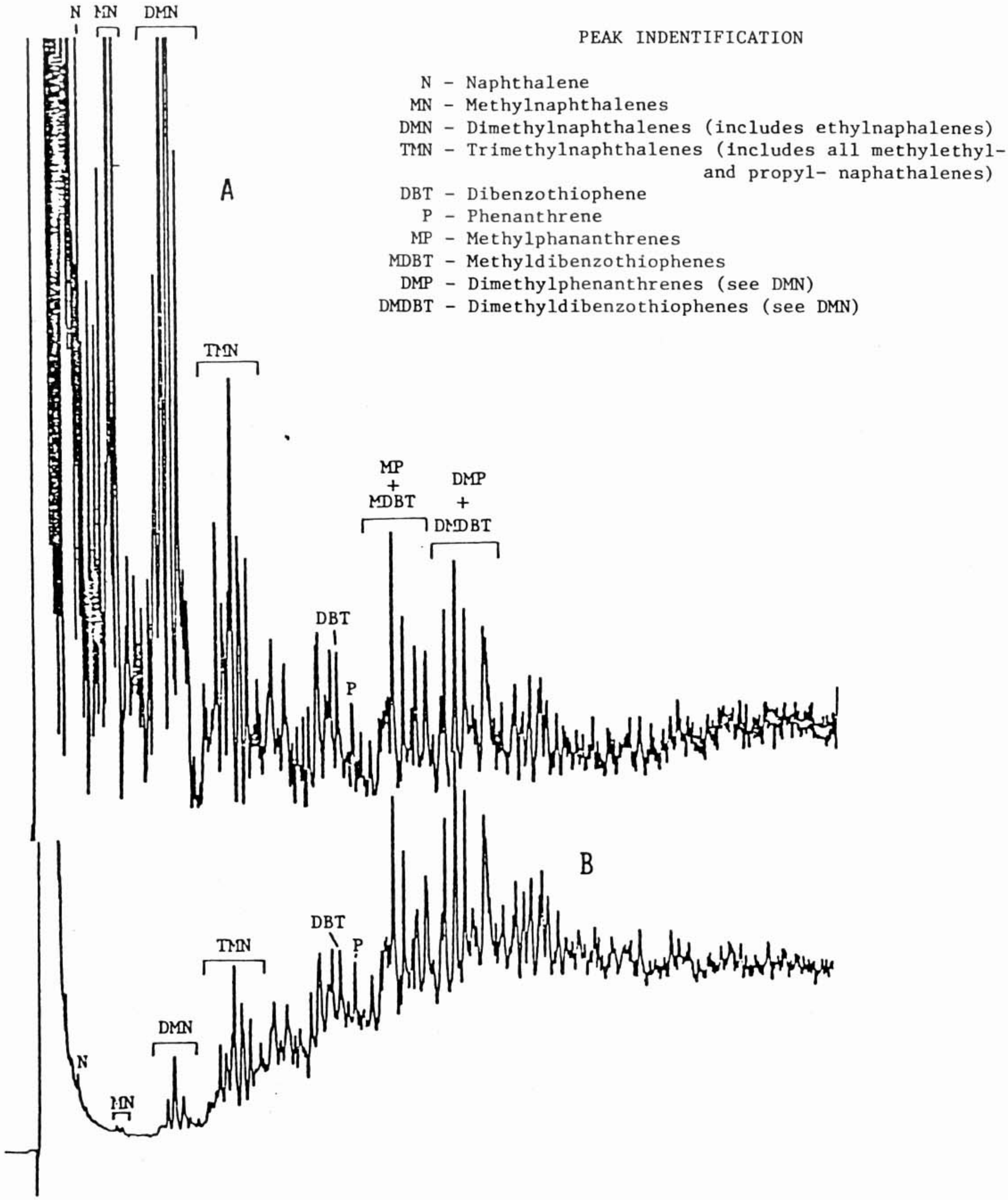


Figure 4. Gas chromatograms of the aromatic fraction of a mousse sample collected 40 hrs after the IXTOC I blowout (A), and the Pt. Baker mousse. (B). (Figure from Parker et al., [1979]).